



NATIONAL WATER QUALITY MONITORING COUNCIL

Working Together for Clean Water

Sensor Signal Integrity and Data Quality Management: Who is Doing What?

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The four levels of signal-integrity assurance

- ▶ Technology
- ▶ Model
- ▶ Instrument
- ▶ Measurement (a.k.a “Activity”, STORET)



Today's focus is on quality assurance actions that occur (i.e., need to be done) at four different levels by a variety of operators.

Level 1: the Technology (Researchers)

- ▶ Discovery of measurement principle, ground-truthing of concept, experiments with prototypes
- ▶ Tests to correlate signal with concentration or magnitude
- ▶ Characterization of capability in terms of linearity, range, interferences
- ▶ Comparisons with other methods that measure the same characteristic
- ▶ Technology demonstrations (e.g., by ACT)

Product: Advanced prototypes, verified operating principles



During the development of new measurement technologies, researchers run tests to prove that the measurement idea actually works and can produce a reliable signal that correlates well with the monitored characteristic. ACT – the Alliance for Coastal Technologies – works closely with developers to conduct demonstrations that focus on the capabilities and potential of emerging technologies.

Example: Technologies for measurement of dissolved oxygen

- ▶ Winkler titration: 1888, Budapest University, doctoral dissertation.
- ▶ Clark-type electrode: early 1950s, Yellow Springs, OH.
- ▶ Quenching of luminescence by dissolved oxygen was noted in 1939, first sensors ("optodes") developed in the 1990s



It is nice to see that we have moved a long way...

The **Winkler titration** is based on a chemical reaction between oxygen and another compound, which yields a product that can be quantified by titration with another chemical. This cannot be done in situ and involves an elaborate analytical process.

The **Clark-type electrode** (a.k.a. polarographic, or galvanic, electrode) utilizes the reduction-oxidation (redox) chemistry of oxygen in the presence of dissimilar metal electrodes. The sensor has an oxygen-permeable membrane that enables diffusion of the gas into an electrochemical cell; a low voltage is applied between the gold cathode and the silver anode and causes the oxygen to react electrochemically. Calibration of the sensor can be done in water-saturated air or oxygen-saturated water, but ground-truthing against the Winkler titration is often recommended as well. Polarographic electrodes revolutionized DO measurements in the field, but the probes (a) consumed oxygen, requiring constant mixing near the membrane's surface [this was somewhat alleviated in the 1980s by rapid-pulse voltage cycles], and (b) needed frequent calibration and maintenance (including assembling the membranes which calls for superior dexterity 😊)

The **fluorescence-quenching "optode"** (a.k.a. Optical DO Sensor) has become available during the last two decades. The probe has a light-source which illuminates an oxygen-permeable membrane made with a fluorescent compound; the reduction in the fluorescence emission due to quenching by oxygen is measured by a light detector. Most optodes are low-maintenance probes that enable prolonged deployments and reliable signal even in harsh environments.

Level 2: the **Model** (Manufacturers)

- ▶ Experiments with materials and parts
- ▶ Selection of shape, probe design, weight, power supply, etc.
- ▶ Characterization of accuracy, precision, resolution, detection limit, and response time, as well as linearity, range, and interferences
- ▶ Incorporation of electronic hardware and software

Product: Manufactured instruments with defined specifications



Next: Thorough testing of Model by others (e.g., ACT)

At the sensor Model level, manufacturers working on building a specific sensor model need to prove the functionality of that model as an established measurement system, and conduct comprehensive tests to derive the specifications for that model.

Example: Model Evaluation by ACT (Alliance for Coastal Technologies)

- ▶ Thorough review of protocols and standard operating procedures
- ▶ Multiple field deployments
- ▶ Determination of accuracy, precision, instrument drift, reliability, and durability, as well as effects and prevention of fouling and other interferences



ACT serves as an unbiased, third party testing entity for evaluation of instrument performance and verification of model specifications. “Verifications are a 25-step process, which includes community consensus on test protocols, laboratory and field-testing, and QA/QC based on EPA and ISO guidelines. Field tests are carried out at no fewer than four but typically all six ACT partner sites.” Among many other things, they check accuracy, reproducibility, instrument drift, and reliability (defined as the ability to maintain integrity of the instrument and the data collections over time).

Level 3: the Instrument (Buyer)

- ▶ Inspection, assembly, deciphering of the manual, and initial operation of the new Instrument
- ▶ Verification of accuracy, precision, resolution, detection limit, and response time at various temperatures and ionic strengths, as well as linearity over specified range.
- ▶ Testing performance in local waterbodies in attended and unattended modes
- ▶ Deciphering the data management software that comes with the Instrument

Product: functional Instrument



"If you think like the developer you can make almost any Instrument work for you"

RK

At the level of an individual Instrument, the Project person who opens the shipment box and prepares the instrument for use needs to go through a series of tests to assure that this instrument is functional and to establish its performance criteria as manifested in the environment relevant to his/her Project.

About the Instrument...

Assumption: “This is an elaborate and expensive (\$10,000!!) sonde [and automatic] [and it has its own brain!]] [and smart!! – see how it identified the Standard Buffer automatically??]; it must always be very accurate, right?”



This assumption is very prevalent and very flawed. You may rely on all the good work that was done by the researchers, the developers, the manufacturers, and the reviewers, but there are so many things you need to check for yourself, and there are so many things your field operators must do when they use the instrument.

Level 4: the Measurement (Field Operator)

- ▶ Reading the User's Manual and SOP!
- ▶ Deployment, retrieval, cleaning, inspection and maintenance
- ▶ Actions to **Affect**, **Check**, **Record**, and **Report** the quality of each data batch
- ▶ Data quality management



Product: Monitoring data of known and documented quality



The fourth level is the Measurement (Activity in STORET language), e.g., a batch of data from one deployment episode. At this level, the field operator is implementing actions to Affect, Check, Record, and Report the quality of each data batch. This fourth level also involves a sequence of Data Quality Management functions, using sensor's diagnostic tests (i.e., physical and electronic operating conditions) to prove signal integrity, and using quality check outcomes to validate the data and to evaluate the extent of error and/or uncertainty.

Calibration: “Comparison of a measurement standard, instrument, or item with a standard or instrument of higher accuracy to detect and quantify inaccuracies and to **report** or **eliminate** those inaccuracies by adjustments” [USEPA].

May [should] be SEPARATED into...

Accuracy check: Comparison of the Instrument’s reading with a value believed to be the “true” value, without adjustments of the reading. **[report]**

Calibration adjustment: The action of adjusting the reading of an instrument to have it match a “true” value. (Naturally, you do this after you run the accuracy check...). **[eliminate]**



Language is important and it needs to be specific.

In other words, actions to Affect are inherently different from actions to Check!



AFFECT



CHECK



Quality Assurance Actions

Affect: Act to influence the outcome

Check: Test to evaluate or verify

Documentation/Communication Actions

Record: Keep everything

documented

Report: Communicate the
Quality Check outcome

ACRR for accuracy (generic)

- ▶ AFFECT – Calibrate
- ▶ CHECK – Conduct accuracy check (compare to Standard)
- ▶ RECORD – Instrument reading + “true” value of Standard
- ▶ REPORT – The difference from “true” value, or % accuracy

AFFECT [Control] <i>(act to influence the outcome)</i>	CHECK <i>(test to evaluate or verify)</i>	RECORD <i>(keep everything documented)</i>	REPORT <i>(communicate the data quality indicator)</i>
Quality Assurance Actions		Documentation Actions	
calibrate (adjustable-reading instruments)	conduct accuracy check (all instruments)	instrument reading and "true" value of Standard	Accuracy (bias): Instrument's difference from "true" value, in measurement units or as a percentage of Standard's value



The table shows a small selection of actions, all related to data accuracy.

ACRR for precision (generic)

- ▶ AFFECT – Use consistent procedures
- ▶ CHECK – Conduct repeated, independent measurements
- ▶ RECORD – Results of repeated measurements
- ▶ REPORT – Relative % difference (RPD, or SD, or CV)

AFFECT [Control] (<i>act to influence the outcome</i>)	CHECK (<i>test to evaluate or verify</i>)	RECORD (<i>keep everything documented</i>)	REPORT (<i>communicate the data quality indicator</i>)
Quality Assurance Actions		Documentation Actions	
use consistent procedures under same conditions	conduct precision checks (repeat measurements of same)	results of repeated measurements	Relative Percent Difference, Standard Deviation, or Coefficient of Variation



Action to Affect, Check, Record, and Report measurement precision are very different from those conducted for accuracy. Both are needed.

(Matrix screenshot)

Technology	data quality aspect	Mode	AFFECT [Control] (act to influence the outcome)	Check (test to evaluate or verify)	Record (keep everything documented)	Report (communicate the data quality indicator)
			Quality Assurance Actions		Documentation Actions	
conductivity cell	Accuracy/Bias	Attended	Conduct one-point calibration in the lab, at a value in the middle of anticipated environmental range, at room temperature [sp1-3], before each Trip. Conduct two-point calibration in the field, at values that bracket expected range, at stream temperature, before first use of the day. Make sure the probe is properly hydrated before calibration and before each use; assure sufficient voltage	Conduct a one-point accuracy check in the lab, at a mid-range value, at room temperature [sp2], within 24 hrs of Trip's end	Temperature of Standard, instrument conductivity reading, temperature compensation factor (if needed), and "true" value of Standard	Report bias: instrument drift, i.e., difference from known ("true") value of Standard, expressed either in measurement units or as percent of Standard's "true" value, whichever is higher.
	Accuracy/Bias	Unattended	Conduct two-point calibration in the lab, at zero and at value higher than expected range, at room temperature, before deployment and at every maintenance event (if needed)	Conduct three-point accuracy check, w/ Standards at min/mid/max values of expected range, plus a zero check in air, at room or field temperature, within 24 hrs of retrieval and at every maintenance event, before and after cleaning.	Temperature of Standard, instrument conductivity reading, temperature compensation factor (if needed), and "true" value of Standard	Report bias: instrument drift, i.e., difference from known ("true") value of Standard, expressed either in measurement units or as percent of Standard's "true" value, whichever is higher.
	Precision	Attended	use consistent procedures under same conditions	Repeat measurements 3-5 times after the reading has stabilized, under controlled (non-changing) environment in the lab, during every calibration or accuracy check event.	Results of the 3-5 measurements after stabilization;	Compute the Standard Deviation of the 3-5 values and report in measurement units [a4]
	Precision	Unattended	Use consistent procedures under same conditions	Repeat measurements 3-5 times after the reading has stabilized, under controlled (non-changing) environment in the lab, during every calibration or accuracy check event.	Results of the 3-5 measurements after stabilization;	Compute the Standard Deviation of the 3-5 values and report in measurement units [a4]
	Lack of interference or contamination	Attended	clean probes			
	Lack/Extent of interference or contamination	Unattended	clean probes, treat with anti-fouling agents, adjust deployment duration or maintenance intervals to local conditions	Run fouling comparison test: Measure stream water (in situ or in bucket) before and after cleaning the probe.	Pre-cleaning inspection and photographic records of fouling, instrument readings before and after probe fouling removal	



I worked with the aquatic sensors workgroup (ASW) to expand the ACRR matrix for all relevant aspects of data quality, and to create a separate matrix of actions for each characteristic and technology.

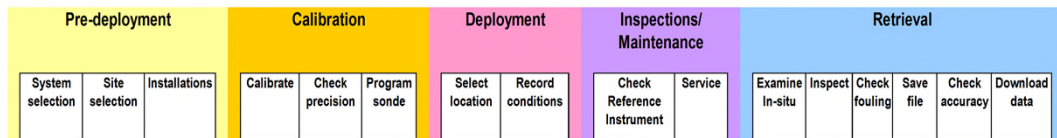
The QA (ACRR) Matrix, ASW 2010

- ▶ ASW and Review Panel recommended the minimum actions required for generation of data of known and documented quality
 - Calibration/accuracy check frequency and number of points
 - Repeated measurements
 - Fouling checks
- ▶ Various aspects of data quality: accuracy, precision, lack/extent of fouling, etc.
- ▶ Attended and unattended modes
- ▶ A page for each WQ characteristic, and a general sensors page
- ▶ Notes and monitoring tips



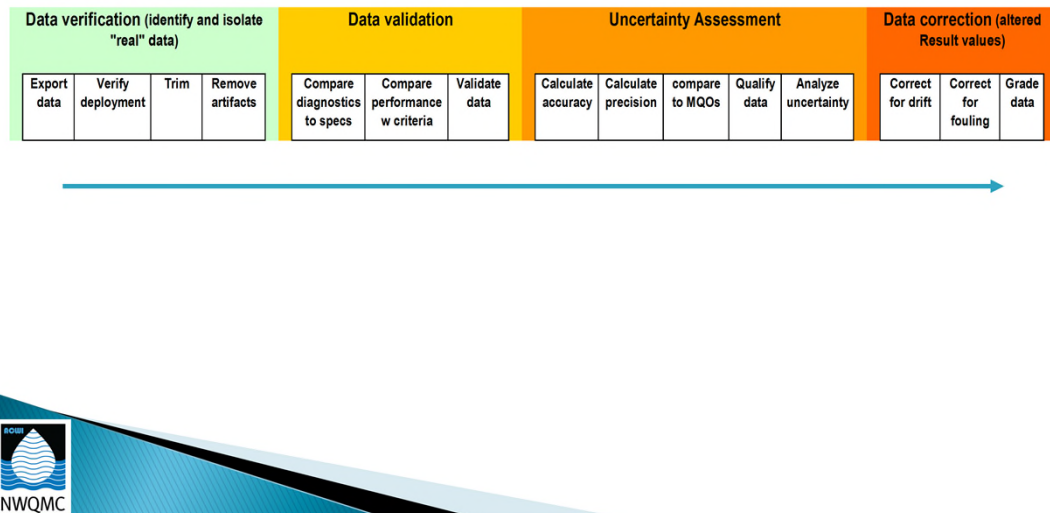
The ACRR matrix is a very useful checklist for field operators seeking concise guidance on how to assure and document the quality of data they are gathering..

The Sensors Data Quality Management (DQM) Functions Timeline, Part 1



Beyond all the ACRR actions, there are a number of other things operators need to do in order to deliver data of known and documented quality. The sequence of Data Quality Management (DQM) functions, shown here as a timeline, includes some ACRR actions embedded in many other functions such as data validation and verification – as also seen in the next slide.

The Sensors Data Quality Management (DQM) Functions Timeline, Part 2



Verification is about making sure that what you deliver as data was indeed a property of the monitored environment (not an artifact). Validation confirms that the measurement system worked properly and according to specifications. Error calculation is part of the validation in that it confirms that the measurement system worked within its performance criteria (i.e., was not broken). Correction of sensor data due to drift or fouling is sometimes called for, and it is important to do the corrections in the same way that other data gatherers do so the data is comparable.

Detail: Calibration and Accuracy Checks

Phase	Calibration			Retrieval					
Task Name	Calibrate	Check precision	Program sonde	Examine In situ	Inspect	Check fouling	Save file	Check accuracy	Download data
Task content	Calibrate electrode w Standard buffers	Run precision check in situ	Program sonde for deployment	document sonde in situ, pre-retrieval	inspect retrieved sonde	run fouling checks in stream water	save and close sonde file	run accuracy checks w Standard buffers	download sonde file to sonde software on computer
Records	'calibration records' package including diagnostics	repeated measurements	Time, place, initial instrument readings	notes (e.g., buried in sediment), photos	notes (e.g., covered w biofilm), photos	readings before and after cleaning	file ID etc.	'accuracy check records' package including diagnostics	file ID etc.
Data Elements subject	7.9.3, 7.9.4, 7.9.5	7.10.1, 7.10.2	5.1.1, 6.4.4	6.4.3, 6.4.6, etc.	6.4.3, 6.4.6, etc.	7.10.1, 7.10.2	6.4.4	7.10.1 to 7.10.4	6.4.4



This is a zoom-in on two phases of the Data Quality Management Timeline. The functions timeline specifies what needs to be recorded with each task, i.e., which “bits of information”, or data elements, need to be captured. The ASW provides a list of Sensors data elements organized by subject matter in seven categories: The Project (who), the Result (what), the reason (why), the time (when), the location (where), the field activity (sample, observation, etc.), and the measurement system (how, and how good).

Sensors data processing, from A to Z



U.S. Geological Survey (USGS) conducted the **Value Engineering Study – Water Quality (2009)**, working with the Interstate Council on Water policy (ICWP); study recommendations included (among others):

- ▶ Automate/streamline data entry and processing
- ▶ Consolidate functionalities of multiple software programs into one solution (identified nine different software programs in use)

More from the Real World: many people are calling for streamlining and consolidation.

Error and Correction

Phase	Uncertainty Assessment					Data correction (altered Result values)		
Task Name	Calculate accuracy	Calculate precision	compare to MQOs	Qualify data	Analyze uncertainty	Correct for drift	Correct for fouling	Grade data
Task content	calculate measurement accuracy for this episode	calculate measurement precision (for this episode?)	compare quality check outcomes to MQOs	select qualifier for 'met MQOs' (or not) or for error range	run an uncertainty analysis	correct data for instrument drift	correct data for sensor fouling	assign a quality-grade to the data based on the extent of correction
Records	Quality check outcome: differential, percent of Standard	Quality check outcome: Relative Percent Difference	values of MQOs	met/did not meet MQOs	confidence intervals or level	algorithm used, date/time corrected		quality grade
Data Elements subject	7.10.2, 2.3.5	7.10.2, 2.3.5	2.3.6	2.3.6	2.3.5	2.3.3, 8.3.1	2.3.3, 8.3.1	2.3.3

Do we have common rules and criteria for data correction?
Do we (should we) use the same correction algorithms and the same grading system?

This is a zoom-in on two other phases of the Data Quality Management Timeline: assessment of uncertainty and data correction. Rules and criteria for data correction, as well as the correction algorithms, need to be the same across the board for data sharing to work.

Correction of Sensors' Data

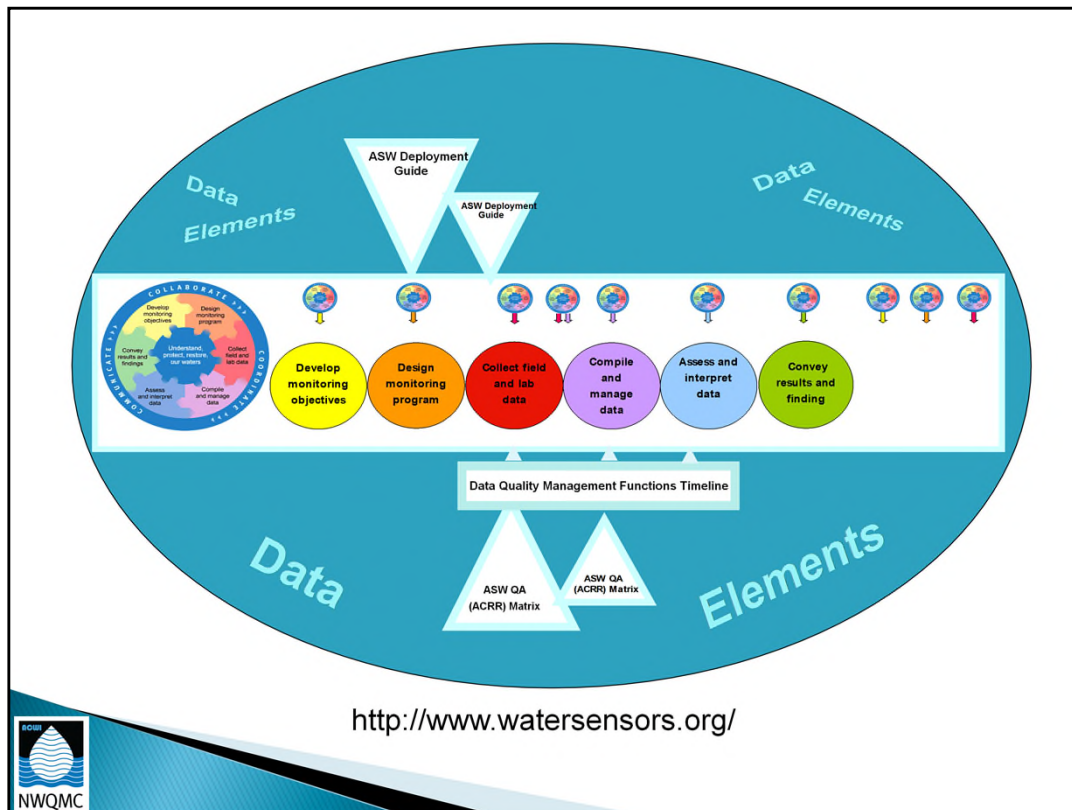
Looked for guidance, tried a number of keyword combinations... Found an internal USGS memo,

“Office of Water Quality Technical Memorandum 2012.04” which talks about
“Auto-correction loader (ACL) Program automates the computation and loading of data corrections directly from SiteVisit into ADAPS”

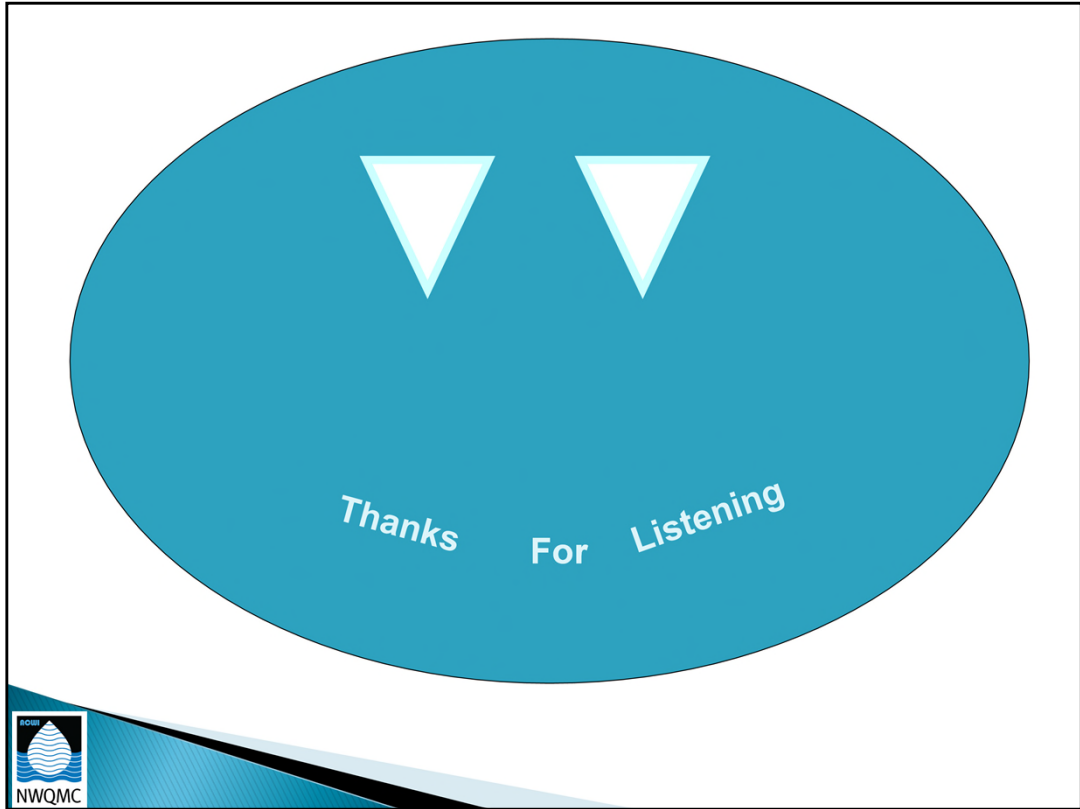
- Problem: these evolving tools are moving targets; rules and criteria for data correction are not permanently established (?)
- Need to improve public accessibility/ease of finding (i.e., relevant information should not be hidden)
- Not all agencies are looking for common tools; some create their own (incompatible?) systems



How many of you tried to find guidance for data correction?



However, the tools that have been introduced by the Aquatic Sensors Workgroup (ASW) are very accessible! The ASW is a workgroup of the Methods and Data Comparability Board affiliated with the National Water Quality Monitoring Council.



Thanks